TITLE OF THE INVENTION

OXYGEN/HYDROGEN GENERATOR FOR INTERNAL COMBUSTION ENGINES

RELATED APPLICATIONS

This application claims priority from Canadian Application No. 2,449,538 filed November 14, 2003.

FIELD OF THE INVENTION

This invention relates to electrolytic oxygen/hydrogen generators, specifically for delivery of combustible gasses to internal combustion engines.

BACKGROUND OF THE INVENTION

It has been proposed to introduce a proportion of hydrogen and/or oxygen into a fuel mixture for burning in an internal combustion engine, in order to increase the efficiency of burning. The intended result is reduced noxious emissions to the environment, reduced engine maintenance and reduced fuel costs.

To date many devices have been proposed for this purpose, but none has come into widespread use.

PRIOR ART

Applicant is aware of the following patents and published applications which pertain to this subject matter:

U.S. Patent No. 4,442,801, to Glynn, et al.;

U.S. Patent No. 4,392,937, to Schmitt, et al.;

U.S. Patent No. 4,028,208, to Giacopeli;

U.S. Patent No. 4,369,737, to Sanders, et al.; and

Canadian Patent No. 1,113,037, to Boulton.

SUMMARY OF THE INVENTION

The invention provides an oxygen/hydrogen generator which includes improved components in a novel structural combination.

In one aspect the invention provides an electrode for use in a hydrolysis cell for generating hydrogen and oxygen gases, comprising a stack of perforated electrically conducting wafers or porous metal filters, vertically spaced from each other, and a connector for connecting each wafer to an electrical circuit. Preferably, the electrode comprises an anode.

In a further aspect there is provided a hydrolysis cell for generating hydrogen and oxygen and which comprises a casing which is at least in part electrically conducting and comprises a first electrode, and has within it a second electrode arrangement as described above. The cell includes means to replenish the cell with water and for removing produced gas. Preferably, the casing comprises the anode and the enclosed electrode is the anode. The means to replenish the cell include a separate water reservoir and a vacuum pump, both in communication with the cell, to evacuate the cell and thereby draw water into the cell. The liquid level within the cell may be detected by a probe which directs a beam of light into the cell, and a detector which discriminates between a first light level in the presence of liquid at the level of the probe and a second light level in the absence of liquid. Upper and lower probes may be provided, with the lower probe optionally including a heater. The water replenishment system may include a four-way ball valve in which the four ports connect with the gas evacuation conduit and the water intake conduit, the valve being either open or fully closed simultaneously to both of the gas evacuation conduits via the vacuum pump and the water intake conduit from the reservoir.

This invention also comprises the systems described in the claims of this patent specification.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other advantages of the invention will become apparent upon reading the following detailed description and upon referring to the drawings in which:

FIGURE 1 is a schematic drawing of an oxygen/hydrogen generator as described in the detailed description;

FIGURE 2 is a plan view of an electrode wafer for use in a lower position within the generator;

FIGURE 3 is a plan view of a second type of electrode wafer for use in an upper position within the generator;

FIGURE 4 is a cross-section through the electrolytic cell of Figure 1;

FIGURE 5 is an assembled electrode assembly, with the central shaft removed for clarity;

FIGURE 6 is a perspective exploded view of a separator disc assembly for mounting between the upper and lower chambers of the cell of Figure 4;

FIGURE 7 is a plan view of the top of cell of Figure 4;

FIGURES 8A and 8B illustrate a physical arrangement of some of the components of the generator and housing;

FIGURE 9 is a schematic drawing of a level sensing device for use in the generator;

FIGURE 10 is a schematic drawing of a slightly modified generator;

FIGURE 11 is a nozzle for use for gas injection;

FIGURE 12 is a front elevational view of a venturi nozzle for directing combustible gasses into a vehicle air intake;

FIGURE 13 is a sectional view along line D-D of Figure 12;

FIGURE 14 is a perspective view of a further embodiment of the invention;

FIGURE 15 is a perspective view of a portion of the embodiment of Figure 14, illustrating in particular the electrolysis cell;

FIGURE 16 is a further perspective view of the electrolysis cell;

FIGURE 17 is a still further perspective view of the electrolysis cell;

FIGURE 18 is a perspective view of an electrode assembly and related components, for use in the embodiment of Figure 14;

FIGURE 19 is a further perspective view of an electrode assembly according to the embodiment of Figure 14;

FIGURES 20A and 20B are perspective views of the reservoir mounting assembly according to the embodiment of Figure 14;

FIGURE 21 is a schematic illustration of the embodiment of Figure 14;

FIGURE 22 is a schematic illustration of an alternative valving arrangement;

FIGURE 23 is a flow diagram illustrating the control subsystem of the system;

FIGURES 24a and 24b provide a more detailed flow chart of operation of the control subsystem.

While the invention will be described in conjunction with illustrated embodiments, it will be understood that we do not intended to limit the scope of the invention to such embodiments. On the contrary, the invention includes all alternatives, modifications and equivalents as may be included within the spirit and scope of the invention as defined by the specification as a whole including the claims.

DETAILED DESCRIPTION

In the following description, similar features in the drawings have been given similar reference numerals. It will be further understood that references herein to dimensions and the like are by way of example only and do not limit the scope of the invention. The drawings are not necessarily to scale.

Referring to Figures 1-9, the generator 10 is illustrated with the electrical connections deleted for clarity, although it will be appreciated that all such connections are present in the article. Generator 10 comprises an electrolysis cell 12 having a liquid inlet 14 and a gas outlet 16. Delivery of water into the cell to replenish the electrolyte liquid is provided by liquid make-up system 18. The generator 10 is housed within a housing 150, described in more detail below, which includes a hatch 140 to provide access to the user-replaceable water reservoir. The housing 150 is suitable for

mounting to an exterior portion of a vehicle, such as a truck cab or alternatively within a vehicle interior.

The cell 12 comprises lower chamber 20 and upper chamber 22, separated by a barrier comprising separator disc 24 which permits gas but not liquids to pass into the upper chamber 22. The upper and lower chambers together form a pressure vessel capable of withstanding pressures generated in the electrolysis system described herein. As is understood in the art, a significant safety margin is provided with respect to the cell integrity. Gases generated within the lower chamber 20 flow into the upper chamber 22 through openings in the separator disc 24, as will be described below.

Lower chamber 20 includes a base disc or bottom 26 which is sealed to the chamber wall.

Lower chamber 20 of electrolytic cell 12 contains anode 28, shown in detail in Figures 2-5. For clarity, anode 28 is partly removed in Figure 1. Anode 28 comprises a stack 30 of electrically conductive horizontally-oriented wafers 32 and 33 (seen individually in Figures 2 and 3). Wafers 32 and 33 are mounted on connector 34 at openings 35 and are vertically spaced on the connector by conductive washers 36. The lower end of connector 34 is fixed to an electrically insulating connector 40 which mounts to base 26 of casing 44 of lower chamber 20. The stack 30 is stabilized by support rods 46 at openings 47, rods 46 fixed to insulating disc 40 and to upper plate 48. Each wafer 32 and 33 is separated from adjacent wafers along support rods 46 by conductive washers 50.

By way of a non-limiting example, the electrode 28 may comprise about 160 wafers 32 and 33 in total, arranged in a stack about 250 mm tall, with spacing between the individual wafers being about 3 mm.

Stack 30 is divided into an upper section 52 and a lower section 54. The wafers 33 of upper section 52 each include a circular aperture 56, with these apertures being aligned to accommodate level sensing device 58. Aperture 56 is absent from wafers 32 of lower section 54.

Wafers 32 and 33 preferably comprise expanded metal discs with stainless steel mesh or expanded stainless steel being found to be particularly suitable. Any suitable metal may suffice, including nickel and

titanium. This expanded metal mesh may have the appearance of ordinary door and window screens. Typically the discs are about or somewhat less than one millimetre in thickness.

Casing 44 is electrically connected to the electrolysis circuit through connector 45 (see Figure 4). The connection is to the grounding circuit of the vehicle and thus enables casing 44 to comprise the cathode.

Separator disc 24, as illustrated in Figure 6, includes apertures 60 and 62 to accommodate connector 34 and level sensing device 58 respectively. Connector 34 and level sensing device 58 are sealed against leakage at apertures 60 and 62.

Separator disc 24 separates the lower chamber 20 from the upper chamber 22 and acts as a seal between the two. The disc 24 includes an annular groove within each of its upper and lower faces to snugly receive the corresponding rims of casings 44 and 64 of the lower and upper chambers. A gasket (not shown) provides a seal. The respective opposing rims of casings 44 and 64 comprise outwardly protruding flanges 45 which respectively contact the upper and lower faces of the disc 24. The flanges 45 and disc 24 are firmly fastened together with a suitable fastener such as a spaced array of nuts and bolts extending therethrough.

Figure 7 also illustrates the use of filters in the separator disc 24 to prevent or reduce egress from lower chamber 20 of moisture and of electrolyte. Thus, apertures 66, 68 and 70 are provided in separator disc 24. As illustrated, the apertures contain, as filters, porous metal alloy discs 71. One suitable porosity range is 5 to 50 microns. A typical material is that sold by Metal Supplies Online, Inc. under the designation "Super Alloy HASTELLOY® C276 alloy"™.

Upper chamber 22 functions as a gas manifold for gases produced in the electrolysis process. As such, the gas conduits for exiting gases communicate with the upper chamber, as will be described.

Top surface 72 of upper chamber 22, seen in Figure 7, contains a number of apertures, although it will be seen that the apertures may be positioned in any convenient location on the wall of the upper chamber 22. Aperture 74 provides sealing and insulating engagement for upper end 76 of connector 34.

Aperture 78 provides sealing engagement for upper end 80 of liquid level sensing device 58.

Aperture 82 connects to gas outlet 16 through gas outlet valve 84.

Aperture 86 leads to pressure regulator 88. Pressure regulator 88 is adjustable over an appropriate range of pressure, typically 10 to 225 psi. Outlet valve 84 is controlled by pressure regulator 88 through microprocessor 152. While operating and output pressure for the cell will vary with specific applications, a typical value for a turbo charged diesel engine would be 50 psi. This is well above normal turbo diesel operating pressures and avoids any backpressure problems due to malfunction.

As described below, microprocessor 152 provides central control over the system. It will be seen that a central controller may comprise any suitable electro or electro-mechanical system which is capable of performing some or all of the logic steps described in this specification.

Aperture 92 connects to vacuum pump 94, the operation of which is also described later.

Finally, aperture 96 connects to a rupture disc 98, which acts as a final safety device. Typically, the rupture disc will blow at a pressure suitably above the cell operating pressure; e.g. 70 psi, or suitably in a range of 50 to 150 psi. However, the selected release pressure may be outside of this range for particular applications.

The seals and gaskets throughout may comprise Teflon™ or other material suitable for forming a seal under the conditions of temperature, pressure and the corrosive electrolytes typically used in such systems.

With reference to gas outlet 16, a conduit 17 leads from outlet 16 at the top 72 of cell 12 through a first run 100 to a moisture collector 102 which condenses moisture from the gas stream. From collector 102, a second run 104 leads to an injector 106 (see Figures 11-13) which may be mounted within an internal combustion engine air intake to deliver hydrogen and oxygen to the air intake. Moisture collector 102 is provided with an electrically operated drain valve 108 to drain collected moisture. The valve may operate on a timing sequence such that, for example, the valve would operate for a very brief period every half hour. Pressure in the line would expel collected moisture, but the timing sequence is sufficiently short as not

to have any material effect on system pressure. Typical operating time may be 0.5 seconds for each ½ hour cycle.

First run 100 of conduit 17 may run from the top of the cell 12 in a direction toward the bottom of the cell 12, with the moisture collector 102 located at the bottom of the run which may be near the bottom of generator 10. The second run 104 then leads back to an upper part of the generator 10 and hence out of the generator and toward the engine. The vertical drop over the two runs 100 and 104 then influences moisture condensing in the runs to flow down into collector 102.

Downstream of second run 104 the conduit 17 includes an additional moisture removing filter 110. This may be a silica gel filled filter.

Conduit 17 also includes a low pressure detector 112.

Conduit 17 enters an internal combustion engine system at a convenient point. This point of entry may be in an air inlet to the engine and may be downstream of a turbo charger. With reference to Figures 11-13, an injection nozzle 114 comprises a dog-leg angled fixture which enters the engine air supply line at a suitable point, and which discharges in a direction parallel to air flow through the line. The discharge point may be on the centre line of the air supply line 116.

The nozzle 114 comprises a venturi which assists in delivering a generally constant flow rate of combustible gasses to an engine intake. The nozzle 114 comprises a first leg 115(a) comprising a substantially cylindrical bore, an end of which receives gas from the conduit 17. The second leg 115(b), communicating with the first leg 115(a) and disposed at a right angle thereto, has an internally tapered bore, the tapering of which increases the speed of gas passing therethrough and decreases its pressure, in accordance with the principle of a venturi. By way of a representative example, the bore tapers from a maximum starting width of 0.437 inches (inside diameter), to a minimum width of 0.188 inches at the throat 115(c) of the nozzle 114. The exit region 115c comprises a narrowed throat region having a generally constant inside diameter. The nozzle 114 includes generally conventional threaded nut and washers for clamping the nozzle with a sealing engagement with a vehicle air supply line. For this purpose, the washers are preferably resilient, for example synthetic rubber or Teflon. The nozzle 114 is

positioned within the inside of the vehicle air supply line, the open end pointing in a downstream direction. When thus arranged, the venturi effect will tend to permit the system to deliver a generally constant flow of gas regardless of fluctuations in pressure within the engine air intake, for example as the engine speed fluctuates. Thus, although in general gas is delivered to the engine at the rate it is produced, rapid intake pressure fluctuations can potentially affect the hydrogen delivery rate over the short term. The use of a venturi in the delivery nozzle tends to lessen these short term fluctuations.

The electrolyte within the cell 12 may comprise any suitable solution such as a solution of potassium hydroxide (KOH) at a suitable strength. The water part of the solution will slowly be used up in the production of hydrogen and oxygen. Accordingly, it is necessary from time to time to add make-up water to the electrolyte to replenish the cell.

Thus, Figure 1 also illustrates a liquid make-up system 18 for cell 12. This system includes a casing 120 and a base 122. Casing 120 includes a mounting 124 for a removable liquid supply bottle 126. Bottle 126 opens into a reservoir 128 within the interior of base 122.

Liquid inlet conduit 15 leads from reservoir 128 in base 122 to the cell inlet 14. Conduit 15 includes a combined heater and temperature sensor 130 and filter 127. Temperature sensor 131 detects a preset low temperature to switch on heater 130. A typical such low temperature preset would be 4°C.

A one-way check valve 125 is provided within line 15 to permit the flow of water into the cell 12 only when the pressure is greater within the reservoir 126 by a pre-set amount. The line 15 may also comprise a water filter 127, for example about 60 micron.

The reservoir 128 includes a level detector 134 to detect liquid level within reservoir 128, temperature sensor 136, and a resistance heater 137.

An incandescent bulb 138 may be mounted inside the casing 120 to serve as a supplemental heater. Alternatively, the bulb 138 may comprise the sole heat source. The bulb 138 is mounted in an electrical socket 139, which in turn is operatively connected to the control system and power source. The temperature sensor 136 may actuate at a predetermined low

temperature to switch on heater 137 and/or bulb 138. A typical such low temperature preset would be 4°C.

Turning to Figures 8A and 8B, a door 140 on casing 120 may incorporate a cutter 141 to pierce the bottle 126 when the door is closed on the bottle, preferably near the top of the bottle, to permit air to enter the bottle as the water is discharged. For this purpose, the bottle preferably comprises a relatively thin, puncturable plastic such as PET of the type commonly used in soda bottles. The bottleneck is sealed with a puncturable seal such as a foil or plastic membrane. The bottle 126 comprises a replaceable, disposable container which is typically supplied to the user pre-filled with distilled water.

As well, base 122 includes a cutter 123 (seen in Figure 22A and described below) to pierce a seal on bottle 126, such as a piercable membrane covering the mouth of the bottle, when the bottle is mounted to the base.

Liquid make-up system 18 delivers water to the cell via a vacuum system 142 which draws water from the reservoir 126 into the cell 12. The vacuum system comprises the vacuum conduit 144 leading from aperture 92 through solenoid valve 146 to vacuum pump 94. Conduit 144 may also include filter 148, which may be a silica gel filter. The vacuum pump 144 when activated by the control system (described below) temporarily evacuates the cell 12. The gas discharge from the vacuum pump vents into the atmosphere through vent 95. Typically, the cell also powers down at this time to prevent further gas formation. However, given the relatively short duration of the recharging cycle, this is an optional step. When the gas pressure within the cell 12 is less than that within the reservoir 126 by a predetermined amount, namely the pressure within the cell 12 is sub-atmospheric, the check valve 125 opens to permit water to flow into the cell 12.

A pressure balance is maintained within water inlet 14, comprising air inlet line 17 which enters the water line 14 at T junction 17(a). Air line 17 terminates in a three-way valve 132. A conventional four-part valve may be used with one port 132(a) plugged in order to permit valve 132 to operate as a three-port valve. A second port 132(b) comprises an air inlet, while the

third port 132(c) is for air to exit the three-way valve into conduit 17. Valve 132 is actuated by solenoid 133. When the electrolytic cell is in normal operation, the valve 132 remains open to equalize pressure within conduit 14 with atmospheric pressure. However, when electrolytic cell 12 is being refilled with make-up water from reservoir 128, valve 132 closes to permit water to flow through conduit 14 under vacuum.

Turning to Figures 9 and 10, the liquid level sensing device 58 also comprises a part of the liquid make-up system 18 for triggering the replenishment of the cell 12 and for re-activating the cell when recharged with water.

In one version, the level sensing device 58 comprises a capacitive float detection system in which each measuring point combines a float and a capacitive sensing system. The level sensing device 58 comprises an elongate upstanding wand 160 having four switch points 162. Each switch point includes a capacitive sensing system 164 embedded within the wand 160 which measures the capacitance of the solution between wand 160 and grounded wall 44 of cell 12. Four floats 166 have a central aperture to slidingly engage the wand 160 and are free to travel vertically within limits defined by upper and lower stops 167 associated with each float 166. Each of floats 166, when in proximity to a respective capacitive system 164, turns on the respective system to recognize the presence of the float. A signal is then transmitted to the microprocessor 152. Each float is free to travel at the electrolyte surface, between positions just above and just below its respective capacitive system, and will be recognized only when immediately opposed to its associated capacitive system.

In one embodiment the capacitive system includes a sensitive amplifier 168 capable of differentiating foam and liquid. Hence, a false reading would not be accepted, should a float ride up on a foam layer. In general, however, the floats are selected so as to not rise upon foam but only on liquid.

As discussed below in the description of the operation of the cell, the levels sensed preferably comprise "full" and "low" levels (indicated as levels 3 and 2 respectively), bounding the normal operating range; and "high shutdown" and "low shutdown" levels (levels 4 and 1), which are assumed to be triggered by a malfunction and thus comprise safety levels.

As seen in Figures 8A and 8B, the generator 10 includes a casing 150 and may be provided with a cooling system to bring ambient air into casing 150 and expel heated air from the casing. The cooling system may comprise one or more cooling fans 149 in a housing 151.

Generator 10 includes a microprocessor 152, which is electrically connected to at least one power supply 154 and to the various described sensors and valves to control the generator. Power supply 154 is also connected to the anode and cathode to power the cell. The power supply 154 receives power from the internal combustion engine electrical system. Power supply 154 is typically operating in the range, or adjustable over the range, of 12 volts/20 amps to 2.5 volts/120 amps.

In one embodiment the power supply 154 operates at full power at 120 amps. Power supply 154 will comprise the alternator of the vehicle electrical system, which supplies power at 12 volts DC at 20 amp to the microprocessor control system, and to another power supply 154(a) comprising a DC-DC converter, which converts the received input (12V DC/20 amp) to an output of 2.5V DC/120 amp. Output from power supply 154(a) is connected to the cathode/anode of the cell 12. The control system controls the switching stages of the power supply (two stages each of maximum output 60 amp) in response to load demand received from the engine RPM sensor.

In another embodiment the power supply is controlled by microprocessor 152 to operate over the range specified above, responsive to engine load.

In operation, the cell 12 will be initially filled to a "full" level with a suitable electrolyte solution. Typically, this can be accomplished by supplying to the user a disposable bottle containing "starter" solution, which consists of the electrolyte solution. This bottle is attached to the reservoir mount 124. The control system is then user actuated to cause the evacuation of the cell 12, which draws the electrolyte from the bottle into the cell 12. Typically, the initial bottle will contain an amount sufficient to fill the cell 12 to a desirable level without any surplus being left in the bottle. This permits the user to then safely discard the bottle. The user then installs a bottle of distilled

water on the mount 124, which is drawn into the cell 12 as the level within the cell drops below a predetermined limit.

On ignition of the internal combustion engine to which the generator is connected, the microprocessor 152 will activate the electrical circuitry causing current to flow through the cell and liberating hydrogen and oxygen in lower chamber 20 of cell 12. The controller detects the engine ignition at 12V DC signal through a "relay circuit" from which an engine starter signal is used to activate the relay coil which activates when the ignition key is turned "on". Subsequently, through a relay auxiliary contact a 12V DC signal is transferred to the processing subsystem input port confirm that the vehicle engine is running.

Once the pressure in the cell reaches the operating pressure, as detected in the pressure regulator 88, the microprocessor signals the valve 84 to open and permit a flow of hydrogen and oxygen to the internal combustion engine.

Operation will continue in tandem with operation of the engine, and the electrolyte level in cell 12 will slowly decrease as liquid is broken down in the electrolysis process to yield the product gas mixture. When the level sensing device 58 detects that the level of electrolyte in cell 12 has reached a "low" level, this information will be transmitted to the microprocessor 152, and the microprocessor will shut down operation of the cell by shutting off power to the cell and initiate the liquid make-up system 18. At all times during operation the system 18 will normally include bottle 126 of make-up liquid, normally distilled water.

The vacuum pump 94 will then be switched on and solenoid valve 146 opened to reduce pressure in cell 12 until it is below atmospheric pressure. Solenoid valve 147 in liquid inlet conduit 14 will then be opened to permit the flow of liquid from bottle 126 to cell 12. Once the level of electrolyte again reaches the "full" level, the vacuum pump will be shut down and solenoid valve 147 also shut down to prevent further inflow of make-up liquid. Check valve 125 also prevents backflow of electrolyte, and is selected to open at 1 psi. The valve 125 is a one-way valve which permits liquid to flow into the cell 12, but not in reverse. Normally, a typical vacuum pump might operate

for less than 20 seconds per fill cycle. The microprocessor will then restart the generator.

Various safety factors may be built into the system, triggered by electrolyte level within the cell. Thus, a high shutdown level may be included such that the microprocessor will shut down the generator should the level sensing device 58 detect that electrolyte has reached that level. Conversely, a low shutdown level may also be provided.

The level detector 134 in base 128 will indicate to the microprocessor and hence to the vehicle operator that the liquid level in the reservoir is low, signalling that bottle 126 must be replaced.

The described temperature sensors will work through microprocessor 152 to control the various heaters as required. This will generally only be at start-up in particular climates.

A further embodiment is illustrated at Figures 14-22. In this version, the gas generator 10 includes a base 200 for supporting the various components herein. The base 200 forms part of the housing 150, the rest of which is not shown to display the internal components. An electrolysis cell 12 comprises a pressure vessel having a liquid inlet 202 and a gas outlet 204. An array of generally horizontal metal fins 206 attached to the exterior of the cell 12 comprise a heat sink for cooling of the vessel. The fins 206 preferably extend but partway around the circumference of the vessel 12 and are spaced apart to provide a degree of air circulation. One or more fans 210 are provided, mounted to a vertical support 212, to direct an air flow at the fins to assist in the cooling process. The cell comprises lower and upper cylindrical and co-axial chambers 220, 222, each having outwardly protruding mating flanges 224 at their opposed rims.

A removable impermanent water reservoir 230 is provided, comprising a removable and replaceable bottle of distilled water. Conveniently, this is mounted in an inverted position, i.e. with its neck and main opening 232 facing downwardly, on a reservoir support 234, which is more clearly shown in Figures 20A and B. The reservoir support 234 comprises a plate supported above the base 200 by legs 236. Flat annular discs 238(a) and (b) are mounted to the upper faces of the support 234. A central internally threaded aperture 240 is centrally disposed in the support 234 to receive a

corresponding threaded neck of a water container 230. The lower, opposed disc 238(b) comprises a somewhat smaller central opening, and supports a membrane-piercing spike 123 which faces upwardly for piercing a sealing membrane 244 of a water bottle. The spike 123 preferably comprises a cone-shaped member having a sharpened upstanding tip, for piercing the membrane 244 as the bottle 230 is screwed downwardly into the central aperture 240. The spike 242 includes openings 246 therein to permit water to flow therethrough into an associated conduit 250 leading from the spike 242. A gasket 252 at the central aperture 240 ensures a leak-proof seal of the water reservoir 230 when screwed tightly thereon. A conduit joins the reservoir 230 to the electrolysis cell 12. A solenoid-controlled two-way valve 253, actuated by the control system 152 controls the flow of water through the conduit. The reservoir support 234 in this embodiment does not include its own reservoir, with the sole reservoir thus comprising the disposable bottle 230. Accordingly, in order to detect water levels within the bottle 230, a level sensing system is provided to signal to the user when the bottle is low and when it is empty and in need of replacement.

When a low level of electrolyte fluid is detected within the cell 12, the vacuum pump 94 is activated to generate a vacuum within the electrolysis cell 12. When a vacuum is generated within cell 12, water is drawn into cell 12 until the "full" level is detected and the vacuum pump is then deactivated.

Preferably, the water reservoir 230 comprises a disposable (recyclable) PET plastic container which may be pre-filled off site with distilled water and provided to the user as a pre-filled, sealed container. Typically, the bottle 230 will hold about 2 litres and requires replacement about every 1000 km of driving, for a typical tractor-trailer truck application. The container has a conventional threaded neck 256, with the container opening being covered by a sealed membrane 258 capable of being punctured by the membrane-puncturing component 123. The container wall is also suitable for puncturing by sharpened member 141 to permit entry of air therein when installed within the system. The unit 10 further comprises an enclosure 120 for partly surrounding and enclosing the water reservoir 230. The removable reservoir 230 and enclosure 120 are sized such that the reservoir contacts the partial enclosure 120 for additional support.

The system further comprises a power supply 154 which is as described in connection with the first embodiment.

The electrolysis cell 12, seen in an exterior view in Figures 16 and 17 comprises upper and lower chambers 22, 20 with the housing of the lower chamber 20 forming the cathode. The housing of the lower chamber 20 comprises a suitable metal such as stainless steel, nickel or nickel-plated steel. The housing is electrically grounded. As seen in Figure 21, disposed within the interior of the housing and effectively lining the inside of the chamber wall is a tubular Teflon™ mesh guard 280, having a perforated sidewall, to separate the reactor core 282 comprising the anode from the housing of the lower chamber 20, which forms the cathode. The reactor anode 282 is best seen in Figure 20. The anode comprises a conductive shaft 284 extending generally vertically the full height of the cell and protruding upwardly therefrom as seen in the first embodiment. The shaft 284 is electrically insulated at points of contact with the chamber by providing an electrically insulating layer over the rod at all points of contact with the cell housing. The anode 282 further comprises a stacked array of porous metal discs 290 comprising metal filter discs such as the Hastelloy™ filter discs described above. The shaft 284 protrudes through central openings 292 within each of said disc 290. The discs 290 are spaced apart by washers 294. The discs 290 are retained on the shaft 284 by a nut 295, which is threaded onto mating threads on the shaft 284. A stack of washers 294 is provided between the nut 295 and the uppermost disc 290. While Hastelloy™ provides a particularly suitable material, it is also contemplated that the filter disc may comprise nickel or titanium, or any other metal suitable for use in the electrode environment. The Hastelloy filter discs comprise 10 micron porous filters made from 316 stainless steel compressed powder.

The base of the anode shaft 284 rests on a Teflon disc 304 resting on the floor of the chamber 20, which electrically insulates the shaft 284 from the vessel housing. At the upper end of the shaft 284, electrical separation is maintained by O-rings, which also form an airtight seal to prevent gas from escaping from the vessel.

As seen schematically in Figure 21, upper and lower sensors 300, 302 protrude into the interior of the lower chamber 20. The lower sensor 302 detects both the liquid level and temperature inside the vessel. The upper and lower sensors 300 and 302 comprise electro-optic sensors, the lower sensor having an embedded RTD temperature sensor to measure a temperature range from between -40°C and 85°C. The electro-optic sensor comprises a light source to direct a beam of light into the chamber and a detector to detect light from the source, which can discriminate between differential light intensity to indicate the presence of absence of liquid within the chamber at the level of the sensor. A preferred embodiment of the sensor comprises an infrared LED as the light source and a light receiver forming an integral probe. Light from the LED is directed into a prism which forms the tip of the probe. When no liquid is present directly in front of the sensor, light from the LED is reflected within the prism to the receiver. When the prism is immersed in liquid, the light is refracted out into the liquid, leaving little or no light to reach the receiver. Sensing this difference, the receiver actuates electronic switching within the unit to transfer the signal to the micro-processor control system. The RTD temperature sensor is connected to an amplifier and signal processor, which provides an output signal to the CPU 152.

The upper and lower sensors each communicate with the CPU 152.

Separation between the upper and lower chambers 22, 20 of the reactor is maintained by a separator disc assembly 24, which rests on the annular upper flange 224 of the lower chamber 20. Resilient O-rings within the assembly 24 maintain a gas-tight seal. An opening extends through the separator disc 24 for the anode shaft 284 to pass therethrough, sealed by additional O-rings. The separator disc 24 includes one or more additional openings 66 to receive metal filter discs 71. These filter disks 71 fit snugly within the openings 66, resting on a shoulder 318. The discs are held in place by threaded lock rings from the top, with opposed resilient O-ring gaskets below the discs to provide a leak-proof seal. The filter discs 71 minimize or block the passage of liquid or foam from the lower reactor chamber 20 into the upper chamber 22. The filter discs 71 are as described above in connection with the first embodiment.

The upper chamber 22 receives combustible gasses which have passed through the filters 71. The upper chamber effectively serves as a gas manifold. A gas exit opening 204 and pressure release valve 326 are each mounted to the upper chamber 22 and communicate with the interior thereof. The pressure release valve 326 is conventional and may comprise a rupture disc as described in the first embodiment.

A heater 138 is provided within the interior of the reservoir housing 150. Conveniently, this may comprise a light bulb, which is electrically connected to the control system 152. As will be discussed below, the system may be arranged such that the heater 138 is activated when the temperature within the housing 150 falls below a pre-set limit, with a manual override to avoid excess battery drain during lengthy periods of vehicle inactivity. Further, a cartridge heater 130 is provided within the water line to elevate the water temperature before it enters the electrode in order to maintain a suitable level of performance.

Gas exits the upper reactor chamber via a gas conduit 330, which leads into a three-way solenoid valve 332 under the control of the CPU 152. In the normal operating mode, gas passes through the valve 332 into a second gas conduit 334, which includes a check valve 336 preferably set at about 50 psi, and discharges into the engine air intake in the manner described in connection with the first embodiment hereof.

In a further aspect, an external reactor heater 380 is provided, comprising a resistive heater disposed within a curved plate partially covering the lower chamber 20 and linked to the system power supply. A temperature sensor built into level sensor 302 detects a temperature below a predetermined set point within the unit's housing, with the heater then being actuated by the CPU 152.

Preferably, the unit 10 may be mounted within the interior of a truck cab such that the heater 380 also serves the function of heating the cab interior during periods of non-use of the truck.

An alternative embodiment of the valve system is illustrated schematically in Figure 22. In this version, a four-way motorized ball valve 360 replaces both of the three-way and two-way solenoid valves of the previous embodiment. Gas exits the upper chamber 22 via gas line 17 and

is piped into the vehicle engine via a check valve and venturi nozzle 114. A second gas conduit 440 exits the upper chamber and enters a first port 360A of ball valve 360. Gas conduit 360B exits ball valve 360 and terminates in vacuum pump 94 for evacuation of the cell 12 in order to draw water into the chamber 20 to replenish the electrolyte. Water exits the reservoir 126 through conduit 440, which leads into port 360C of ball valve 360. Water then may exit through port 360D, via conduit 442 through check valve 444 and nozzle 14 into the lower chamber 20. the ball valve includes an internal motor to actuate the internal ball, not shown, which directs flow through the ports in the manner described below. The ball valve is operatively linked to the CPU 152 for operation in response to inputs in a manner similar to that described above.

In operation, the ball valve 360 normally dwells in a first position wherein all ports 360A-D are closed and gas exits the upper chamber via conduit 17. When the lower chamber 20 is ready for replenishment, all ports 360 A-D open and the vacuum pump 94 is actuated. This rapidly evacuates the cell 12, thereby drawing water into the chamber 20 through conduits 440 and ports 360C and D. When the chamber has reached its full level, as detected by the level sensor 300, the ball valve 360 shuts all ports and the vacuum pump 94 shuts down, thereby resuming normal operation of the system.

The signal processing unit 152 will now be described by reference to Figures 23 and 24A and B. The CPU 152 comprises a microprocessor programmed to carry out the functions described herein. The microprocessor 390 receives signal input from a variety of signal generating subsystems as follows: The reactor vessel comprises under and over temperature sensors which transmit a signal at respective set points such as 7°C and 40°C as upper and lower limits. The upper and lower liquid level sensors 300, 302 transmit respective signals to the CPU 152, when actuated by the liquid within the lower chamber 20 reaching respectively a set upper limit or a lower limit. Conveniently, the upper limit is within about 230 mm from the base of the reactor vessel 20, while the lower limit provides a level wherein the electrolyte still fully covers the anode discs 290. An under-pressure sensor within the interior of the vessel is provided. This under-pressure

switch or sensor is mounted on the top of the reactor and is preset at about 10 psi. Upon activation of the system, a lag time of 10 minutes is permitted during which the cell may power up to 10 psi. However, if the internal pressure does not exceed 10 psi within 10 minutes, this indicates a leak within the system and the under-pressure sensor transfers a signal through its normal closed contact which triggers identification of this problem to the central control subsystem. However, if the pressure exceeds 10 psi after 10 minutes, then the switch reverts to an open position, and the system is considered ok and no signal is transmitted to the central control subsystem.

An open door sensor detects when the hatch has been left open. The CPU 152 will shut down the system until the hatch has been fully shut.

The CPU 152 communicates via a data link such as a USB 400 to a computer 402 which stores historical system data, which may be retrieved when necessary. Alternatively or in addition, a wireless communication 404 may be provided to a system monitor 406, which displays operating parameters of the system to a user and permits a user manual system override.

The CPU 152 controls the electrically driven components, including the various heaters 130, 137, 138, cooling fans 210, solenoid and ball valves, main power supply and water reservoir pump. The microprocessor comprises a logic system which operates according to the diagrams which form Figures 25 and 26A and 26B. Figures 24A and 24B form right and left halves of a detailed single diagram. Table 1 provides notes to aid in the understanding of Figure 26. Figure 25 represents a simplified flow chart indicating the inputs and outputs of the CPU 152. Figures 24A and B describe the functioning of the CPU in response to the various inputs.

Table 1

Inputs

A = G2 = Ignition

B = G8 = Unit low temperature

C = G9 = Reservoir Low temperature

D = G10 = Supply Line Low temperature

E = B7 = Reservoir Low Level

F = B8 = Reactor Low Pressure

H = B10 = System High Temperature

I = G4 = Door Sensor

Outputs

R = B6 = Power Supply

S = G5 = Pump

T = 2 Way Valve

W = B1 = Heaters (supply line, reactor, and reservoir heaters)

X = G6 = 3 way gas valve

Y = G5 = Cooling Fans

Z = G4 = Bulb (acts as a heater and turns on when door is open)

J2-1 = Low Low Level (LL)

J2-2 = Low Level (L)

J2-3 = High (H)

J2-4 = High High (HH)

<u>Notes to Table 1</u>

Note that the "1" and "0" written beside the LL, L, H, HH shows whether the level is ok or not. 1 is for OK, and 0 is for Not Ok. The bottom two floats are "OK" if the floats are floating, and the top two floats are "OK" if they are sinking.

Also note the diamond shape box which states, "If LL&L". This shows 2 states at the same time. The four levels are shown beside this state, and they are, Low Low (LL), Low (L), High (H), High High (HH)

Trade-marks: "Jet Fuel" is a trademark. It describes distilled water. "Jet Star" is a trade-mark for the electrolytic system.

Note 1: This particular action in the system deals with replenishing the reactor with water. The process stops when there is no need for more water in the reactor, and this is determined by the floats. The process can also be

stopped if it takes more than 30 seconds for the process to stop, which ever comes first.

** All field inputs such as {(G-8), (G-9), (G-10), (B-7), (B-8), (B-10)} have to be time delayed for (2- sec) before activating any received error

** All inputs of (J2) connector such as {(J2-1), (J2-2), (J2-3), (J2-4)} have to be time delayed for a (5- sec) before activating any received error

Microprocessor Functions

System off:-

Make sure that input (G-2) is off AND all outputs such as (G-5), (G-6), (B-1), (B-4), (B-5), (B-6) are off then send a command signal to the receiver unit [Ignition Off]

** If input (G-8) = 0 (v), then turn on output (G-4) until the input is cleared. Monitor the status (G-4) through the internal lamp circuit. If output (G-4) found to be blown, then send a command signal to the receiver unit [Change Light Bulb].

** If input (G-9) is on, then turn on output (B-1) and send message to receiver [E205], until the input is cleared, if not turn off output (B-1) after 3600 (sec).

System on:-

Ensure that input (G-2) = +12 (v), then monitor the following inputs {(G-8), (G-9), (G-10), (B-7), (B-8), (J2-4)}are not on and (J2-1), (J2-2) floats are ok, then turn on output (G-6), (B-6), then send a command signal to the receiver unit [Jet Star Running].

** If input (G-8) is on, then turn on output (G-4) until the input is cleared. Then monitor the output (G-4) through the internal lamp circuit. If output (G-4) found to be blown, then send a command signal to the receiver unit [Change Light Bulb].

else turn off output (G-4)

** If input (G-9) is on then turn on output (B-1), until the input is cleared, then monitor the following inputs {(G-8), (G-10), (B-7), (B-8), (J2-

4), (J2-1), (J2-2)} are ok, if any of the previous inputs found to be not ok, then jump and execute its assigned sequenced subroutine, else turn off (B-1). If input (G-9) not cleared after 3600(sec), turn off output (B-1) and send message to receiver [E205].

** If input (G-10) is on, then double check if input (G-9) on too, if so, then turn on output (B-1). Until the input is cleared, then monitor the following inputs {(G-8), (B-7), (B-8), (J2-4) (J2-1), (J2-2)} to check if they are ok. If any of the previous inputs found to be faulty, then jump and execute its assigned sequenced subroutine, else turn off (B-1). If input (G-10) not cleared after 3600(sec), turn off output (B-1).

** If input (B-7) is on, then turn off output (G-6), (B-6) and (B-5), then send a command signal to the receiver unit [ADD Jet Fuel] until the input is cleared, then monitor the following inputs {(G-8), (G-9), (G-10), (B-8), (J2-4) (J2-1), (J2-2)}, if any of the previous inputs found to be giving an unwanted signal, then jump and execute its assigned sequenced subroutine, else turn on output (G-6) and (B-6).

** If input (B-8) is on after 600 (sec) from turning on output (G-6) & (B-6), then turn off output (G-6) & (B-6) for 5 (sec), then monitor the following inputs { (G-8), (G-9), (G-10), (B-8), (J2-4) (J2-1), (J2-2) to make sure they are ok, if any of the previous inputs found to be unwanted, then jump and execute its assigned sequenced subroutine, else turn on output (G-6) & (B-6). Retest for 3025 (sec) if input (B-8) found is still on Turn off output {(G-6), (B-6), (B-4) and (B-5)}, then send a command signal [E203].

** If input (B-10) is on, turn on output (G-5) until the input is cleared, then monitor the output (G-5) through the internal circuit. If output (G-5) found to be blown, then send a command signal to the receiver unit [E206] else turn off output (G-5).

For the J2 switches, all the following inputs {(J2-1), (J2-2), (J2-3), (J2-4) }need to be delayed by 5 (sec) before activating any error. If input (J2-1) or (J2-2) not ok for more than 20 (sec), then turn off output (G-6), (B-6), (B-4) and (B-5), then send a command signal to the receiver unit [E207].

** If input (J2-1) is not ok & (J2-2) is ok and (J2-3) ok, OR if input (J2-1) & (J2-2) are both not ok, then turn off output (G-6), (B-6), (B-4) and (B-5), then send a command signal to the receiver unit [E200].

** If input (J2-2) not ok & input (J2-1) is ok & (J2-3)is ok, turn off output (G-6) & (B-6), then turn on output (B-5)(also check to see if B-5 is working through the internal circuit, if not working send to the receiver [E202]), after 5 (sec) turn on output (B-4), then after 25 (sec) OR when input (J2-1) & (J2-2) & (J2-3) are ok and, then turn on output (G-6) & (B-6), then monitor the following inputs {(G-8), (G-9), (G-10), (B-7), (B-8), (B-10)} to make sure they are ok, if any of the previous inputs found to be unwanted, then jump and execute its assigned sequenced subroutine, then if input (J2-2) & (J2-1) not ok OR if (J2-1) not ok and (J2-2) is ok & (J2-3) is ok then turn off output (G-6), (B-6), (B-4) and (B-5), then send a command signal to the receiver unit [E200].

** If input (J2-4) not ok for 20 (sec), then turn off output (G-6), (B-6), (B-4) and (B-5), then send a command signal to the receiver unit [E207].

<u>Summary of Error Messages for Program</u>

E200 = Low Low Reactor Level
E201 = High High Reactor Level
E202 = Pump Failure
E203 = Low Pressure
E205 = Heater Run Time
E206 = Cooling fan failure
E207 = Level Control Fault

It will be seen that detailed aspects have been described in the detailed description and drawings presented herein. This detailed description is intended merely to illustrate particular aspects and embodiments of the invention. It is not intended to limit the full scope and spirit of this invention, which is more completely realized in the claims which follow, including all equivalents to the elements and features described or mentioned in the claims.